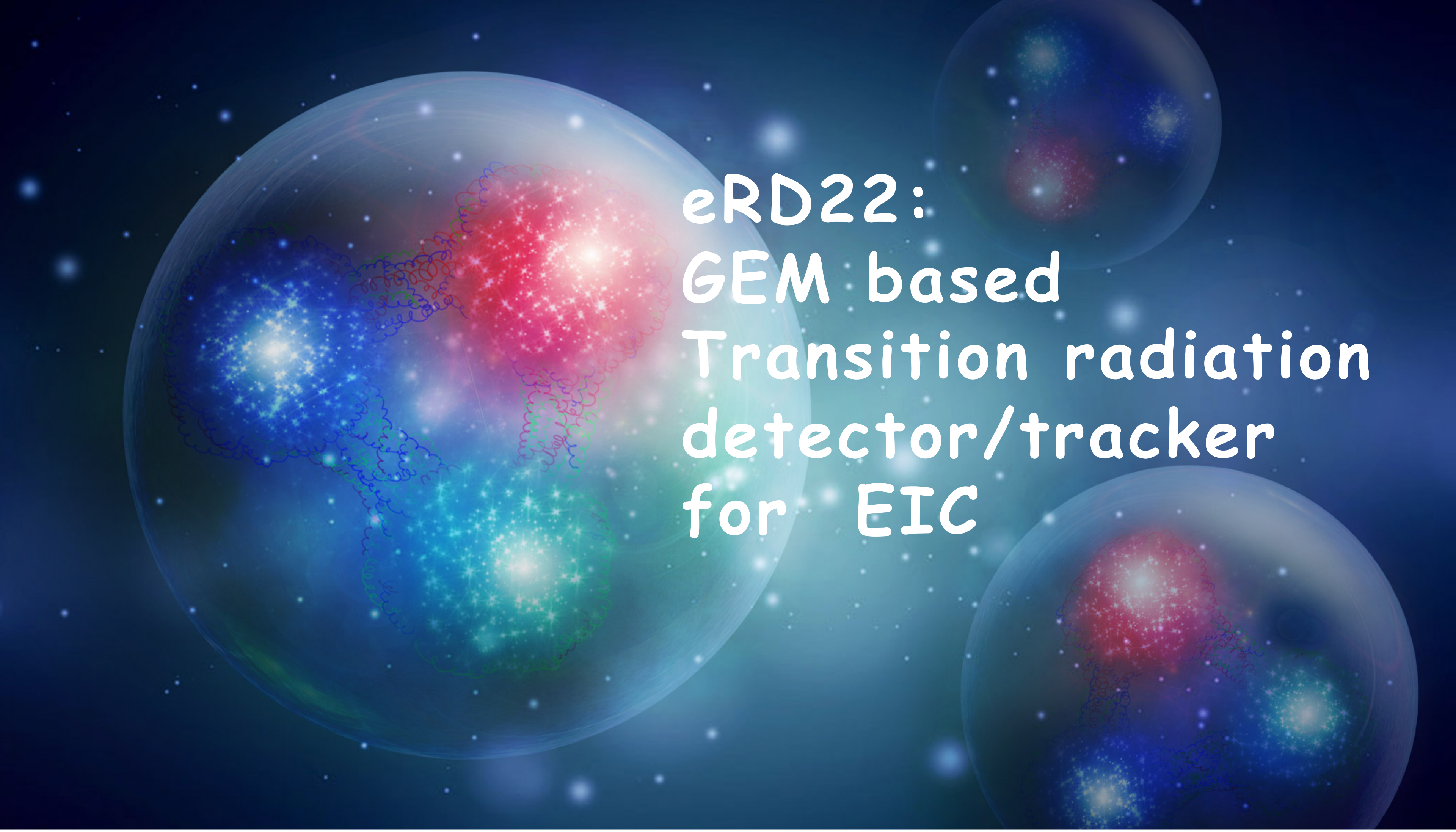


eRD22: GEM based Transition radiation detector/tracker for EIC

Yulia Furletova (JLAB) on behalf of GEM-TRD/T working group

GEM-TRD/T TEAM:

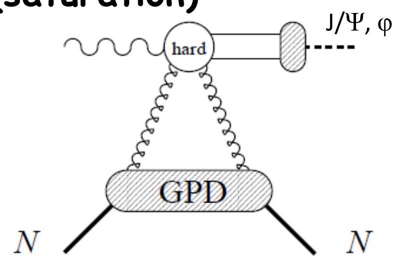
- Jefferson Lab:
  - ✓ Howard Fenker
  - ✓ Yulia Furletova
  - ✓ Sergey Furletov
  - ✓ Lubomir Pentchev
  - ✓ Beni Zihlmann
  - ✓ Chris Stanislav
  - ✓ Fernando Barbosa

- University of Virginia
  - ✓ Kondo Gnanvo
  - ✓ Nilanga K. Liyanage

- Temple University
  - ✓ Matt Posik
  - ✓ Bernd Surrow

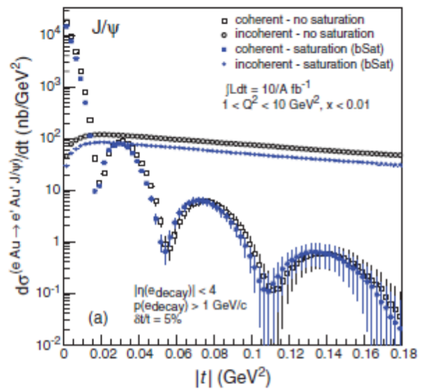
Electron identification (e/hadron separation)

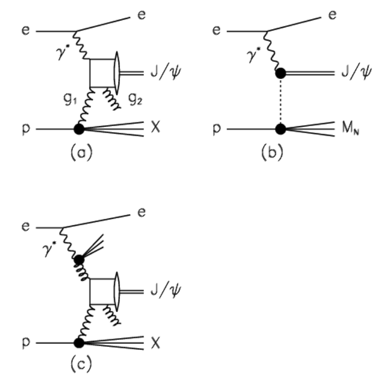
- GPD and Coherent Exclusive Diffraction (saturation)



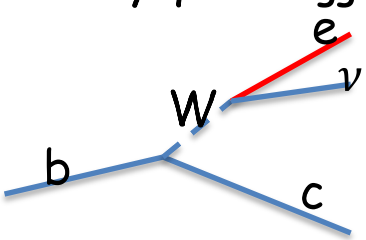
Br (J/ψ->e+e-) ~6%

Br (J/ψ->μ+μ-) ~6%



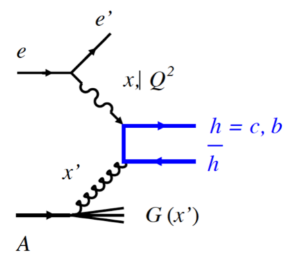


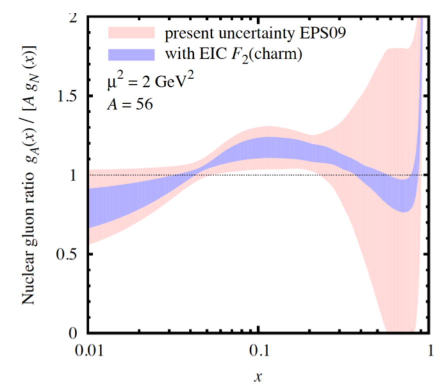
- Heavy quark tagging



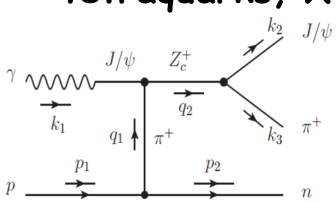
Br ($D^{\pm}$->e+X) ~16%

Br ($B^{\pm}$->e+ν+X_c) ~10%





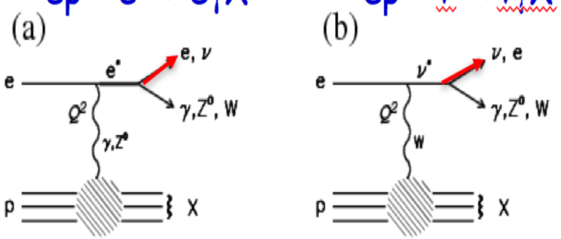
- Exotic spectroscopy (pentaquarks, tetraquarks, XYZ)

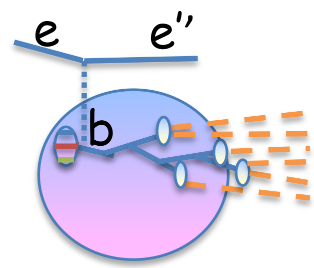


- Other BSM physics

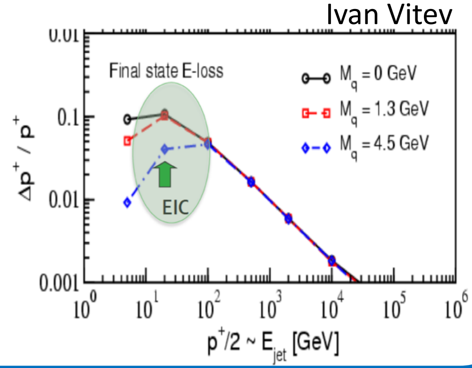
ep-> e*-> eγX

ep-> ν*->νγX





Ivan Vitev

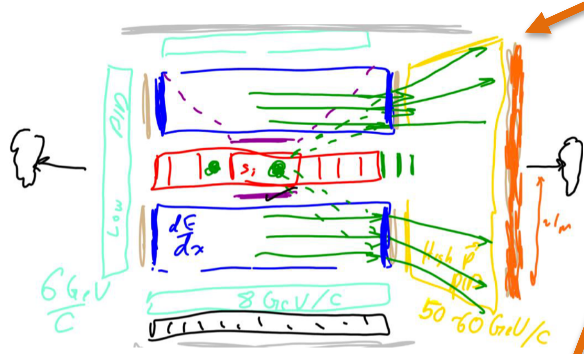


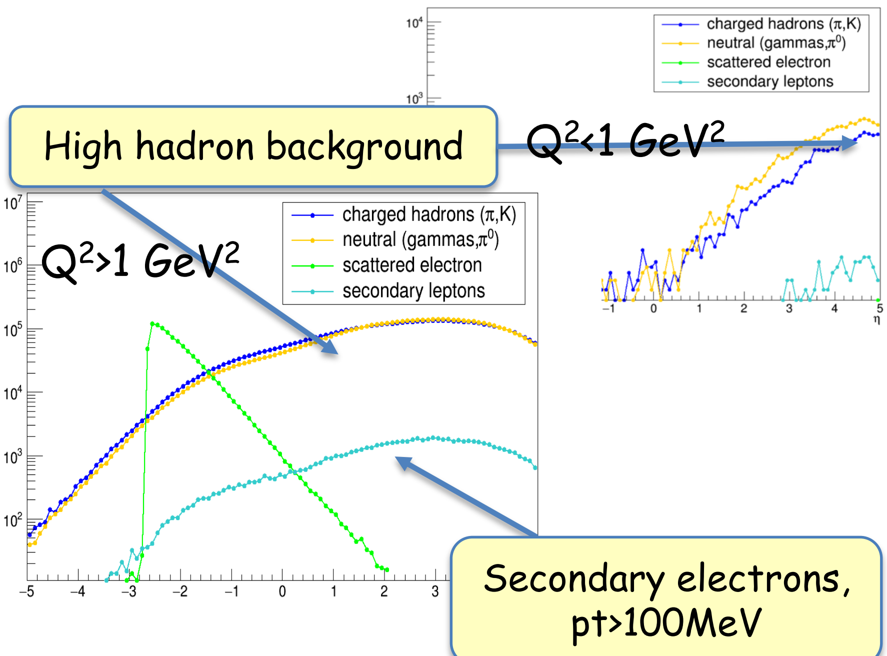
Electron/hadron separation

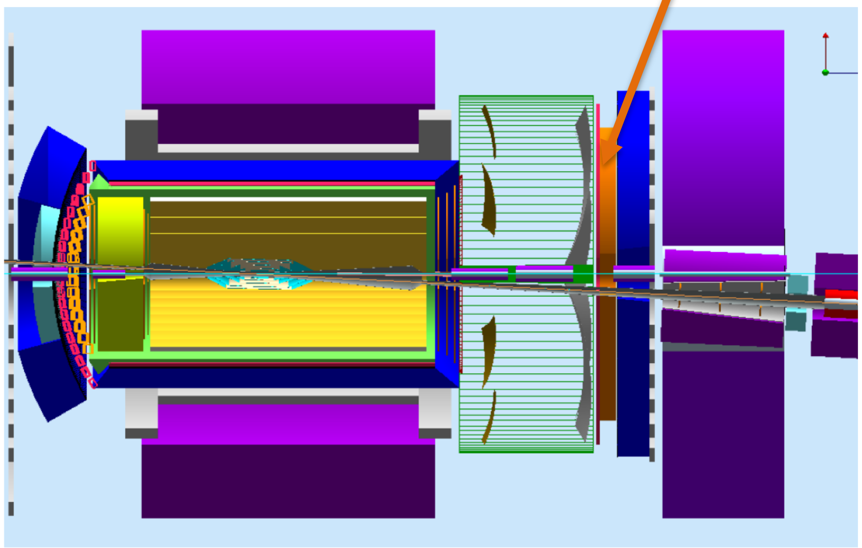
- The main detector for e/hadron separation is a Calorimeter. Also dE/dx in tracking detectors, as well as Cherenkov detectors could be used in the limited momentum range.
- At EIC (hadron end-cap) e/h rejection factor > 500-1000 is required.
- TRD offers high e/h rejection for electrons in 1-100 GeV range

- Hadron end-cap
- between dRICH and EMCAL (extra tracking point)

GEM-TRD/T





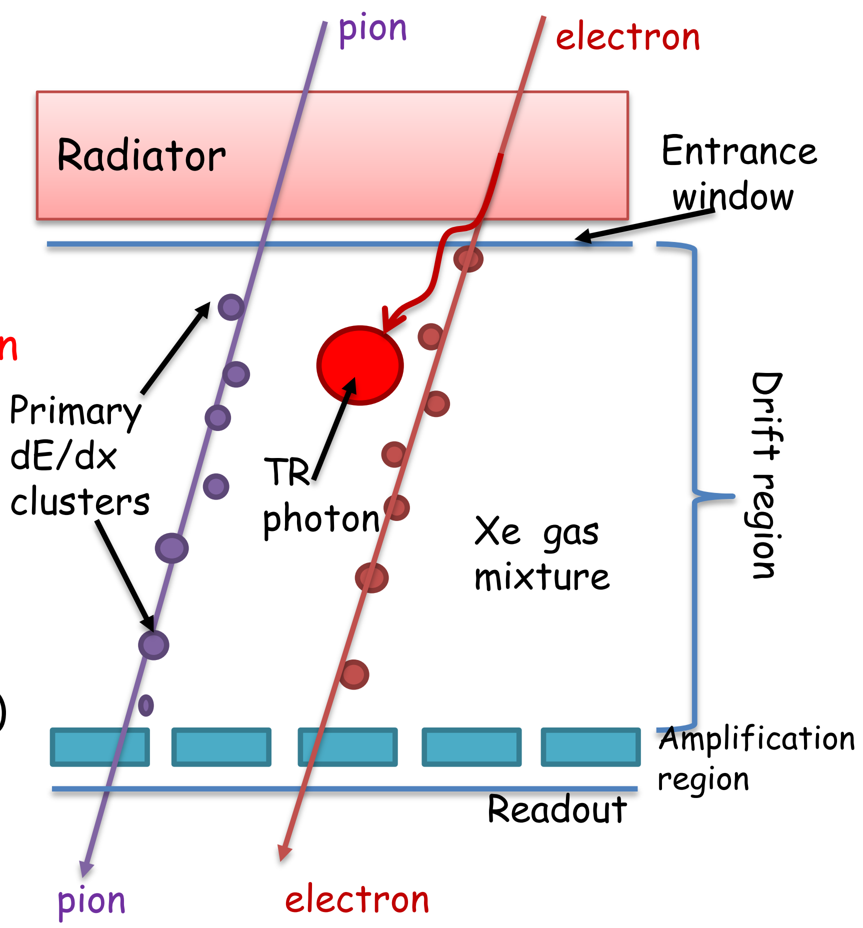


Yulia Furletova

4

GEM as Transition Radiation detector and tracker for EIC

- High resolution tracker.
- Low material budget detector
- How to convert GEM tracker to TRD:
  - ✓ Change gas mixture from Argon to Xenon (TRD uses a heavy gas for efficient absorption of X-rays)
  - ✓ Increase drift region up to 2-3 cm (for the same reason).
  - ✓ Add a radiator in the front of each chamber (radiator thickness ~5-20cm)
  - ✓ Number of layers depends on needs: Single layer could provide e/pi rejection at level of 10 with a reasonable electron efficiency.



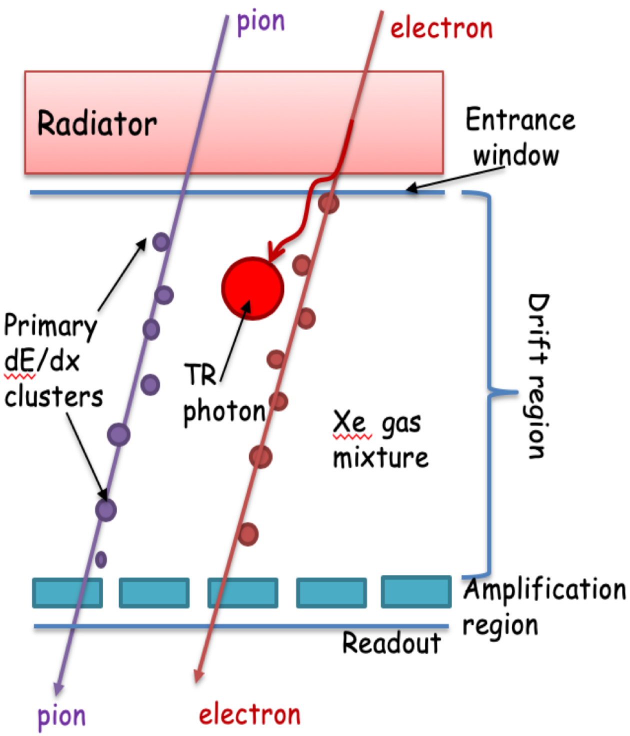
Was planned to do within FY19:

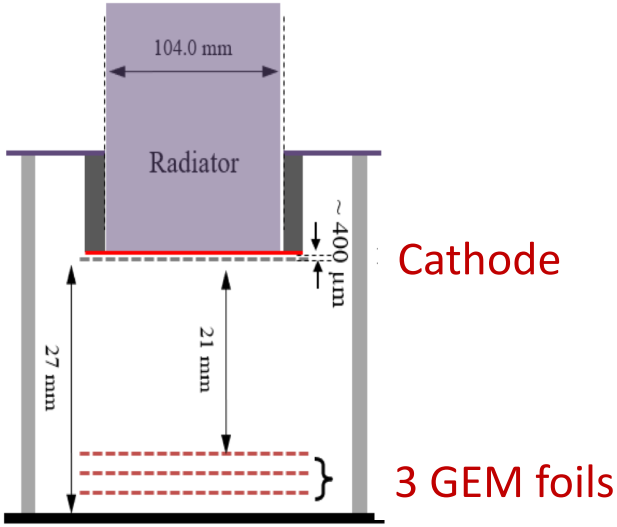
- Continue Monte Carlo simulation and data analysis (main recommendation from eRD committee)
- Test Module with different (%) gas mixtures: gas system is ready. Test gas-mixture for contaminations.
- Test Cr module: new prototype is ready and under a test at UVA
- Collaboration with tracking and streaming readout consortia
- Planning to present our results at conferences and prepare a publication

GEANT4 standalone : electron and pion comparison

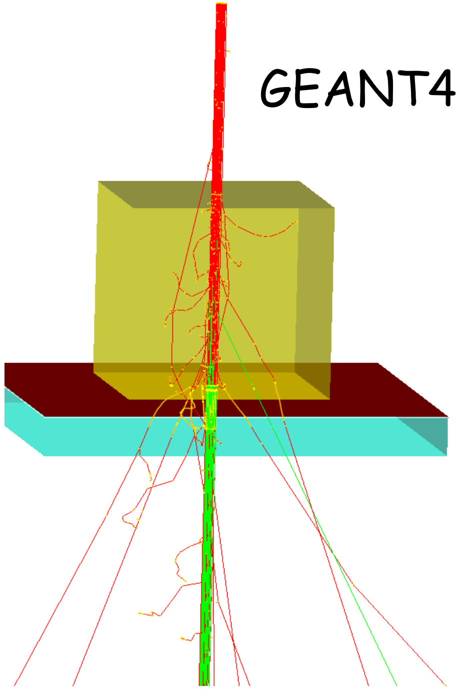
Parameters:

- ✓ Detector Gas Volume (Drift region) : 1 – 4 cm
- ✓ Radiator Volume (R): 3-10 cm
- ✓ "Dead material": needs to be minimized (source of inefficiency) !
    - ✓ entrance window (Mylar 50μm)
    - ✓ cathode material(Al, Cu, Cr)
    - ✓ gap (Xe filled) 400μm (need dedicated field-cage)
- ✓ Gas mixture: Xe/CO_2 , Ar/CO_2 …





GEANT4



Geant-for-EIC (g4e) as a tools for integration of sub-detectors into a global detector system.

- Almost all sub-detectors within eRD have their own standalone GEANT4 simulation (detector geometry descriptions, material, sensitive detector description, digitization, etc… as well as a reconstruction code….

- A lot of discussions with EICUG and eRD20 (software consortia) about a common tools for EIC. See my more detailed talk about g4e at EIC Ad-hoc Meeting on detector and physics simulations) https://indico.bnl.gov/event/6336/

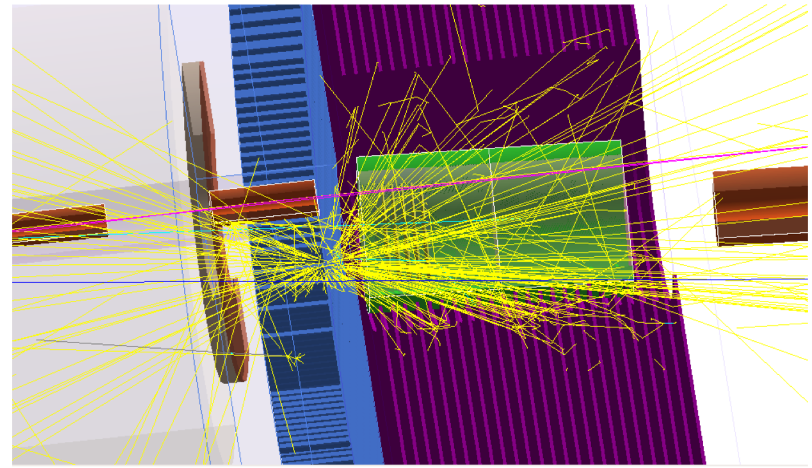
- Historically started as a standalone simulation for vertex detector for EIC (for open charm search), and then extended by including other sub-detectors (straw –tube tracker, EMCAL, beam elements, etc….)

- And now a layer of TRD has been added.

- Looking forward to collaborate with software consortia (EICUG, eRD20)

GEANT4: integration of TRD into a global detector setup (g4e)

GEM-TRD is integrated into "g4e" version of JLEIC detector



Detector description/construction

Configuration structure:

- include
- src
- design
- all
  - cb_CTD
  - cb_DIRC
  - cb_EMCAL
  - cb_HCAL
  - cb_Solenoid
  - cb_VTX
    - cb_VTX.hh
  - ce_EMCAL
  - ce_GEM
  - ce_MRICH
  - ci_DRICH
  - ci_EMCAL
  - ci_GEM
  - ci_HCAL
  - ci_TRD
    - ci_TRD.hh
  - ffe_CPOL
  - ffe_LUMI
  - ffi_ZDC
  - fi_EMCAL
  - fi_TRKD1

```
#include "JLeicDetectorConfig.hh"


struct ci_TRD_Config {
// define here Global volume parameters
    double RIn = 20 * cm;
    double ROut = 200 * cm;
    double ThicknessZ = 40 * cm;
    double PosZ;
    G4double fRadZ;
    //-----------------------------
    double fGasGap = 0.600 * mm;    // for ZEUS  300-publication
    double fRadThick = NAN;
    int fFoilNumber = NAN;
    //-----------------------------
    double det_RIn = 50 * cm;
    double det_ROut = 100 * cm;
    double det_ThicknessZ = 2.5 * cm;
    double det_PosZ;
    G4double fDetThickness;
    G4double fDetLength;

    double fAbsorberThickness = 0.050 * mm;
    double fAbsorberRadius = 100. * mm;
    double fAbsorberZ = 136. * cm;
    double fDetGap = 0.01 * mm;
    int fModuleNumber = 1;
    G4Material *fRadiatorMat;        // pointer to the mixed TR radiator material
    G4Material *det_Material;

    G4double fRadThickness = 0.020 * mm;    // 16 um // ZEUS NIMA 323 (1992) 135-139, D=20um, dens.= 0.1 g/cm3
```


Yulia Furletova

GEANT4: integration of TRD into a global detector setup (g4e)

TR-radiator and gas absorber are described

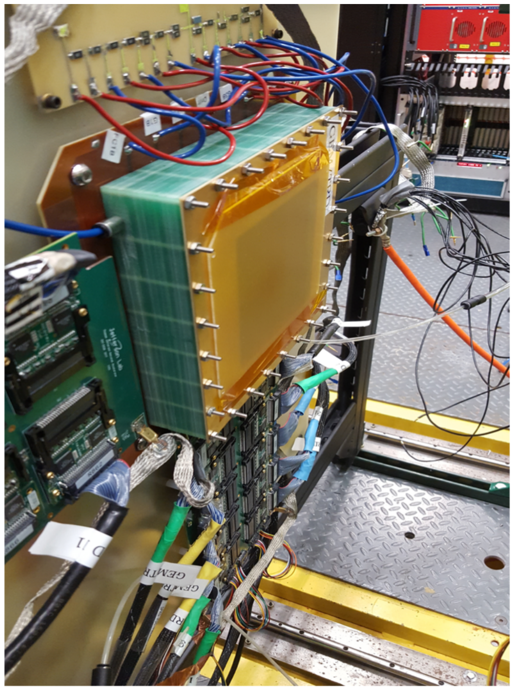
```
G4cout << "use for Rad totDensity = " << totDensity / (g / cm3) << " g/cm3 " << G4endl;

G4double fractionFoil = foilDensity * foilGasRatio / totDensity;
G4double fractionGas = gasDensity * (1.0 - foilGasRatio) / totDensity;
G4Material *radiatorMat0 = new G4Material("radiatorMat0", totDensity, 2);
radiatorMat0->AddMaterial(CH2, fractionFoil);
radiatorMat0->AddMaterial(Air, fractionGas);
G4double NewDensity = 0.083 * (g / cm3);
G4Material *radiatorMat = new G4Material("radiatorMat", NewDensity, 1);
radiatorMat->AddMaterial(radiatorMat0, 1.);
G4cout << "new  Rad with totDensity = " << NewDensity / (g / cm3) << " g/cm3 " << G4endl;

G4double XTR_density = radiatorMat->GetDensity();
G4cout << "Read back Rad totDensity = " << XTR_density / (g / cm3) << " g/cm3 " << G4endl;
// default materials of the detector and TR radiator
cfg.fRadiatorMat = radiatorMat;
fFoilMat = CH2; // Kapton; // Mylar ; // Li ; // CH2 ;
fGasMat = Air; // CO2; // He; //
-----------------------material ------------------------------

cfg.fRadThick = 10. * cm - cfg.fGasGap + cfg.fDetGap;

cfg.fFoilNumber = cfg.fRadThick / (cfg.fRadThickness + cfg.fGasGap);

printf("fFoilNumber1=%d \n", cfg.fFoilNumber);
cfg.fRadZ = -cfg.ThicknessZ / 2 + cfg.fRadThick / 2 + 2 * cm;

foilGasRatio = cfg.fRadThickness / (cfg.fRadThickness + cfg.fGasGap);

fSolidRadiator = new G4Tubs("ci_TRD_Radiator_Solid", 50 * cm, 100 * cm, 0.5 * cfg.fRadThick, 0., 360
fLogicRadiator = new G4LogicalVolume(fSolidRadiator, cfg.fRadiatorMat,
                                     "ci_TRD_Radiator_Logic");

attr_ci_TRD_rad = new G4VisAttributes(G4Color(0.8, 0.7, 0.6, 0.8));
attr_ci_TRD_rad->SetLineWidth(1);
attr_ci_TRD_rad->SetForceSolid(true);
fLogicRadiator->SetVisAttributes(attr_ci_TRD_rad);

fPhysicsRadiator = new G4PVPlacement(0,
                                     G4ThreeVector(0, 0, cfg.fRadZ),
                                     "ci_TRD_Radiator_Phys", fLogicRadiator,
                                     Phys, false, 0);
```

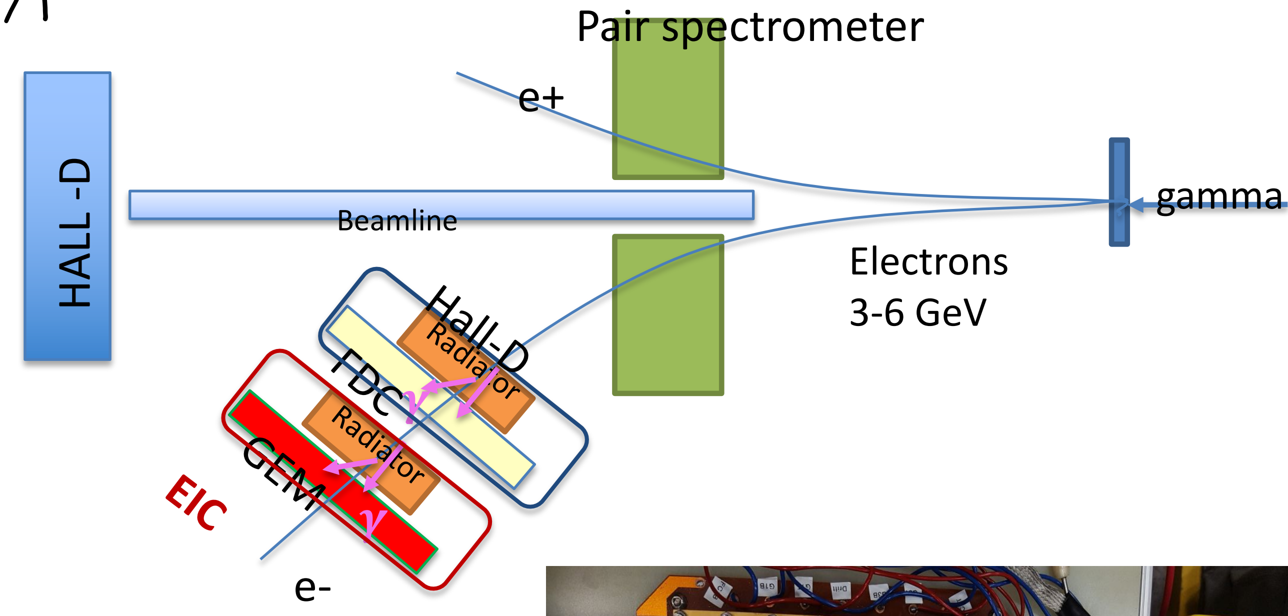
TR process is included into a physics list :

```
void JLeicPhysicsList::ConstructEM()

// G4cout<<"fMinElectronEnergy = "<<fMinElectronEnergy/keV<<" keV"<<G4endl;
// G4cout<<"fMinGammaEnergy = "<<fMinGammaEnergy/keV<<" keV"<<G4endl;
G4cout<<"XTR model = "<<fXTRModel<<G4endl;
std::cout<<"XTR model = "<<fXTRModel<<G4endl;

const G4RegionStore* theRegionStore = G4RegionStore::GetInstance();
G4Region* gas = theRegionStore->GetRegion("XTRdEdxDetector");

G4VXTRenergyLoss* processXTR = 0;

if(fXTRModel == "gammaR" )
{
  // G4GammaXTRadiator*
  processXTR = new G4GammaXTRadiator(pDet->GetLogicalRadiator(),
                       100.,    //-- AlphaPlate 100
                       100.,    //-- AlphaGas   100
                                 pDet->GetFoilMaterial(),
                                 pDet->GetGasMaterial(),
                                 pDet->GetFoilThick(),
                                 pDet->GetGasThick(),
                                 pDet->GetFoilNumber(),
                                 "GammaXTRadiator");
}
else if(fXTRModel == "gammaM" )
{
  // G4XTRGammaRadModel*
  processXTR = new G4XTRGammaRadModel(pDet->GetLogicalRadiator(),
                                 100.,
                                 100.,
                                 pDet->GetFoilMaterial(),

}
else if (particleName == "e-")
{
  // Construct processes for electron
  theeminusStepCut = new JLeicStepCut();
  theeminusStepCut->SetMaxStep(MaxChargedStep) ;
  //theeminusStepCut->SetMaxStep(100*um) ;
  G4eIonisation* eioni = new G4eIonisation();
  G4PAIModel*     pai = new G4PAIModel(particle,"PAIModel");
  eioni->AddEmModel(0,pai,pai,gas);

  pmanager->AddProcess(new G4eMultipleScattering,-1,1,1);
  //pmanager->AddProcess(new G4eMultipleScattering,-1,-1,-1);
  pmanager->AddProcess(eioni,-1,2,2);
  pmanager->AddProcess(new G4eBremsstrahlung,-1,3,3);
  pmanager->AddDiscreteProcess(processXTR);
  pmanager->AddDiscreteProcess(new G4SynchrotronRadiation);
  pmanager->AddDiscreteProcess(theeminusStepCut);

}
```

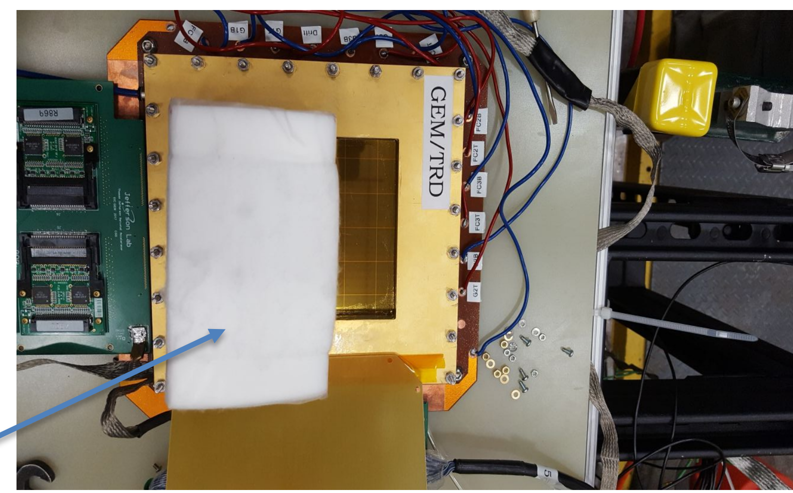
GEM-TRD/T prototype test setup

- A standard Cu-GEM-TRD/T prototype is currently under tests
- A new Cr-GEM-TRD/T





- 3-6 GeV electrons in Hall-D from pair spectrometer
- In parallel with Hall-D MW-TRD (FDC) system
- covered ½ of the sensitive area with radiator

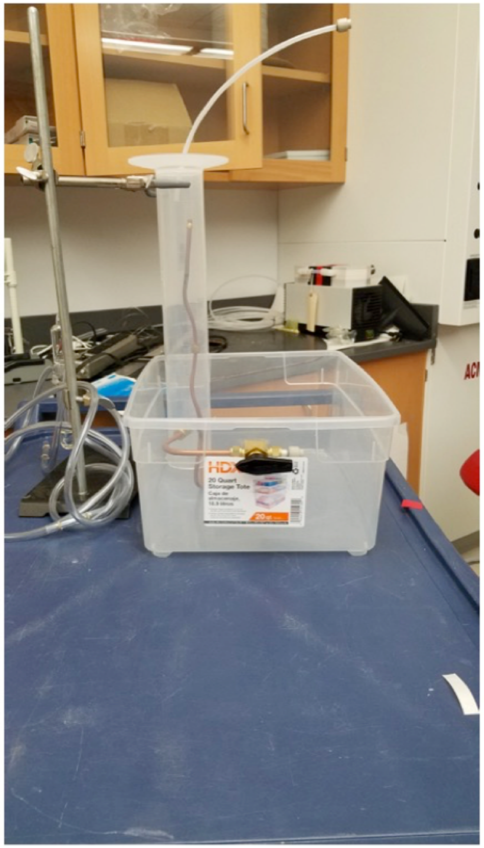


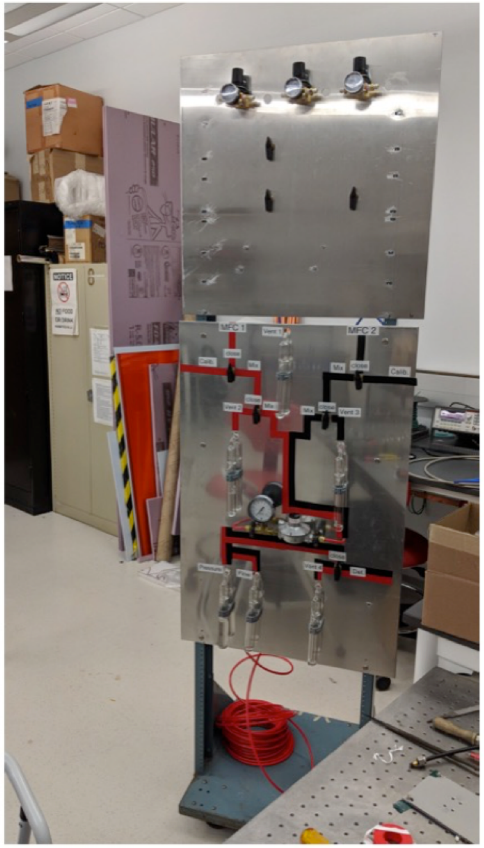
Gas system

- Without a re-circulation and a purification system (too early stage of R&D)
- Mixing system to mix custom gas concentrations
- Flow controller, CO_2 controller

➢ Assembled at Temple U.

➢ Delivered to JLAB (hall-D) in Jan 2019





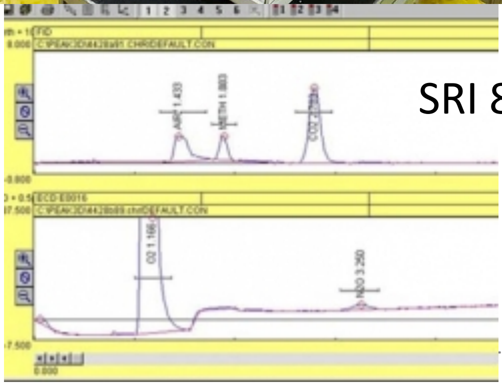
➢ waiting for a final approval for safety and operation under pressure (all necessary parts are ordered, expecting approval in Sept)

Gas quality monitoring system

We purchased gas analyzer to begin quantifying and monitoring contaminations and to measure the concentrations of the Xe and CO_2 gasses.

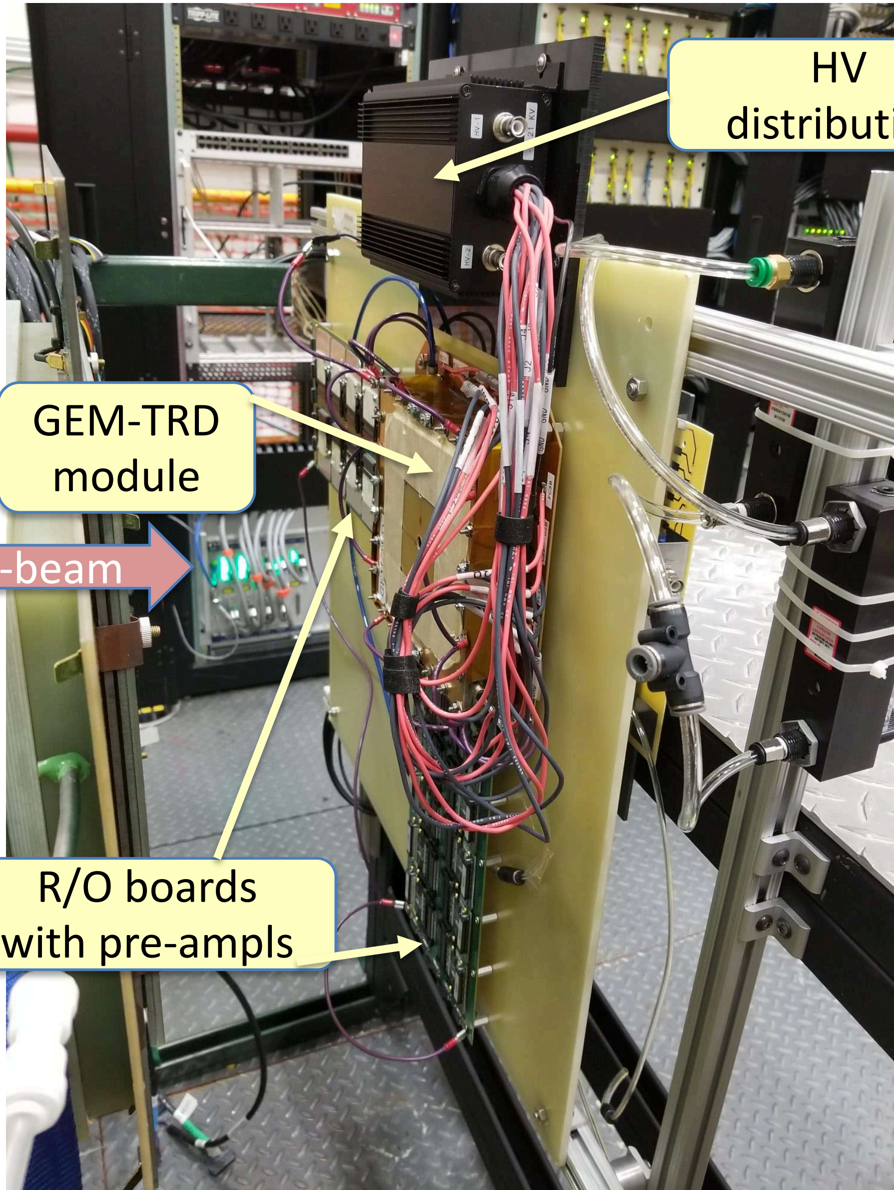
-> split a cost with Hall-D : our contribution $7k (40%) to extend up to Xe

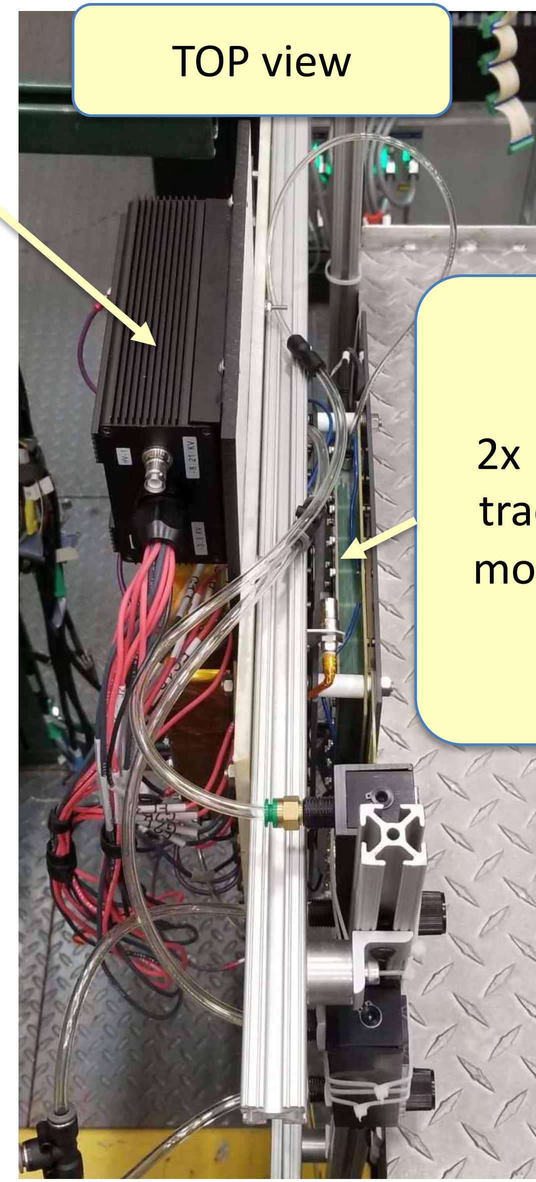
Helium gas as carrier



SRI 8610C

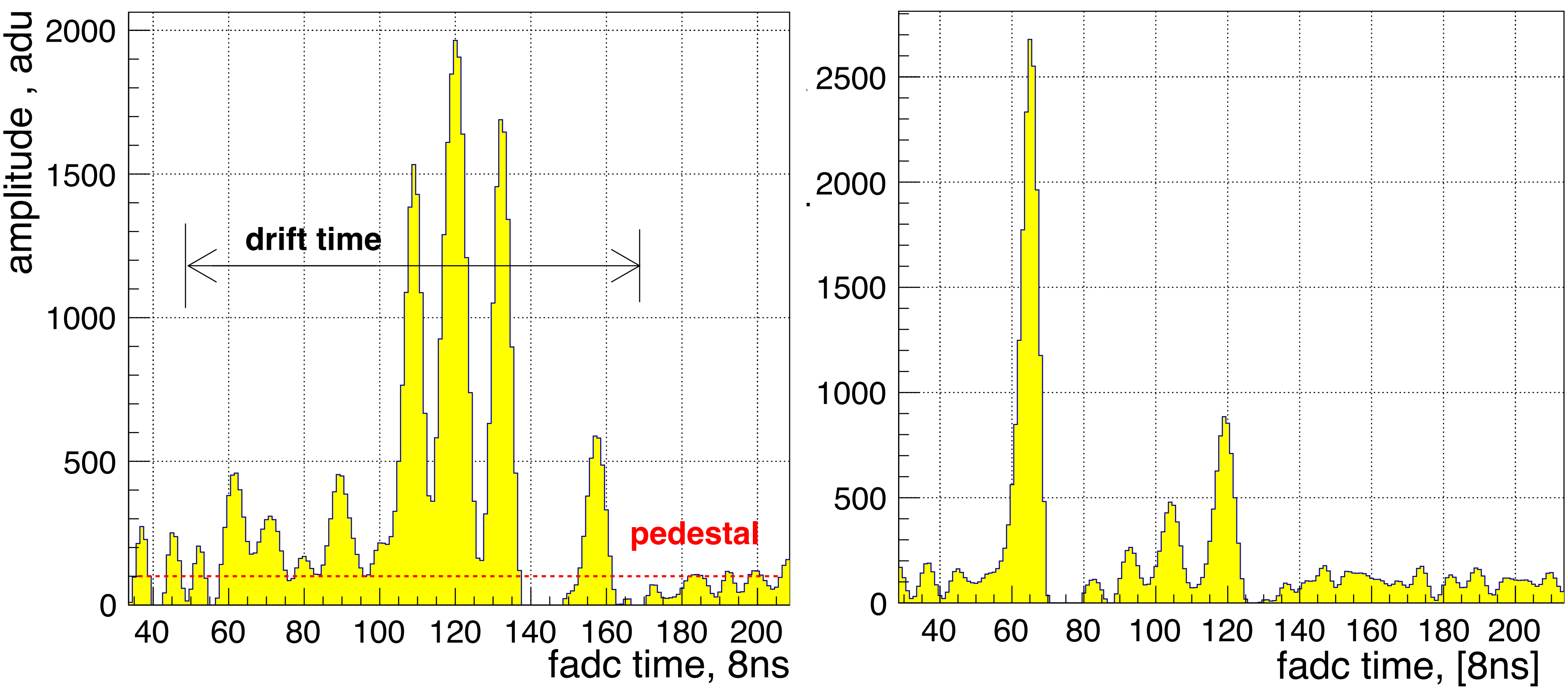
Tracking: preparation for a spring test setup



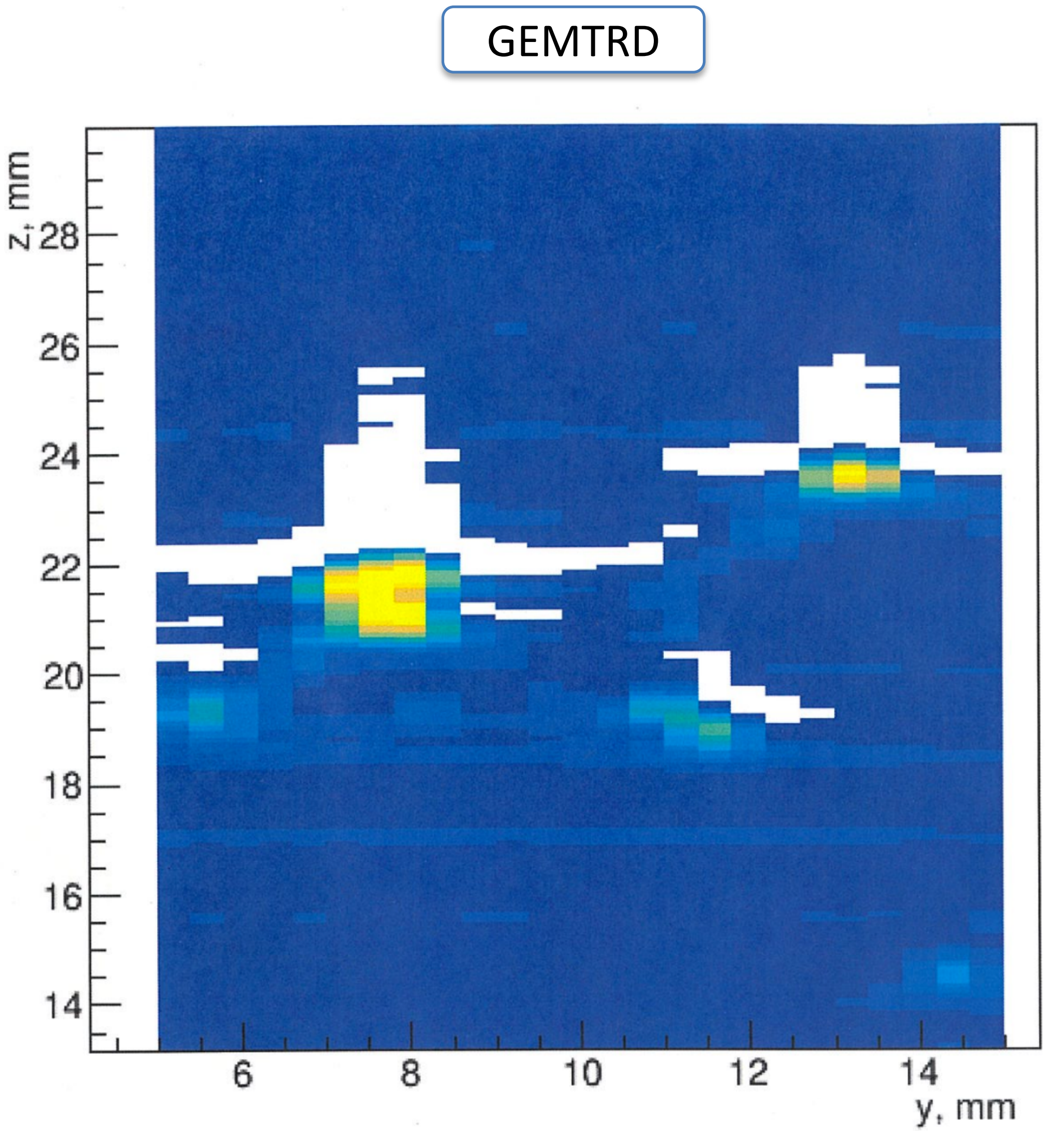


Readout electronics

- ✓ FlashADC 125MHz setup shows excellent performance!
- ✓ Pre-amplefiers : undershooting, no base-line restorer !!!
- ✓ Collaboration with eRD23 (streaming readout) to find the best solution for GEM-TRD operation in a streaming mode



Readout electronics: undershooting

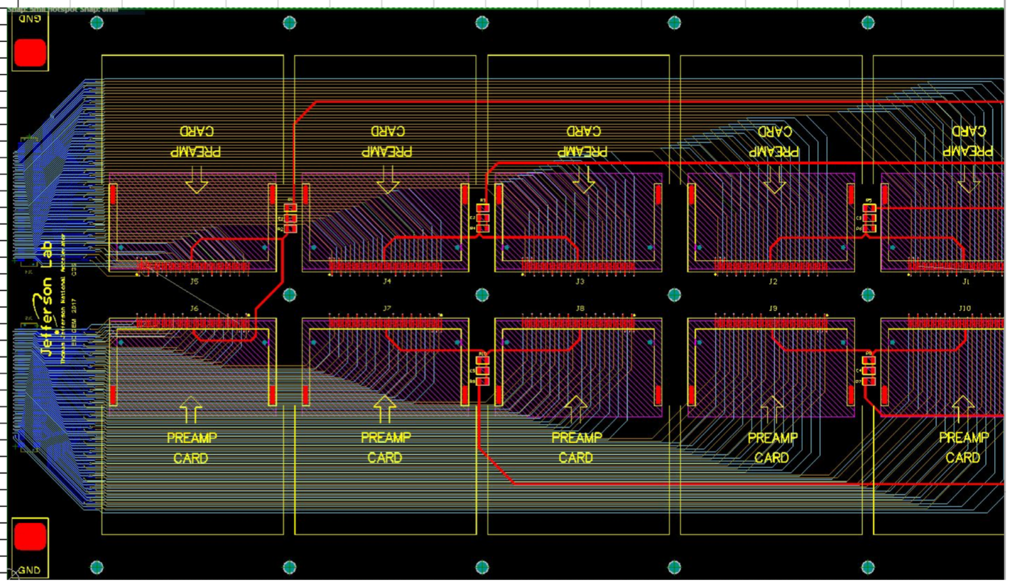


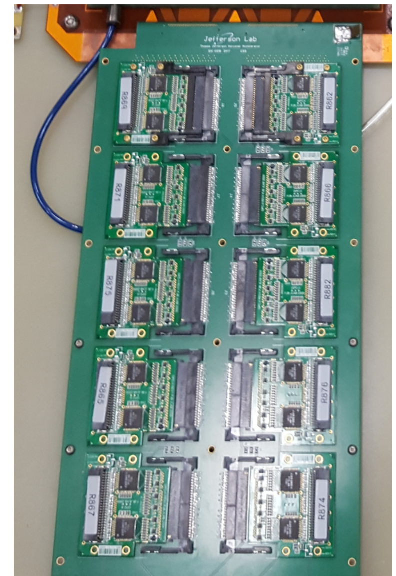
Undershooting creates a visible area of inefficiency (or signal losses)

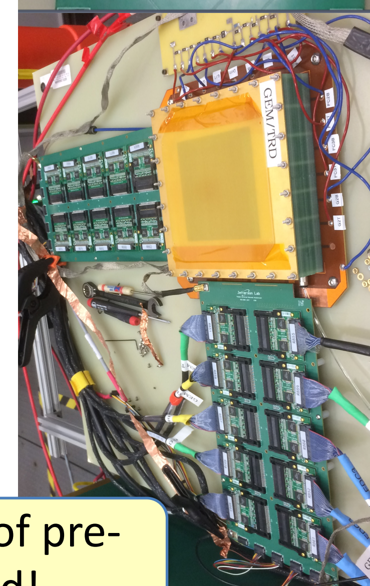
New interface board For GEM-TRD

Fernando Barbosa and Chris Stanislav

J15	Channel	Pre-Amp	Pre-Amp Pin
1	GND		
2	CH121	J6	50
3	CH122	J6	49
4	CH123	J6	48
5	CH124	J6	47
6	CH125	J6	46
7	CH126	J6	45
8	CH127	J6	44
9	CH128	J6	43
10	CH129	J6	42
11	CH130	J6	41
12	CH131	J6	40
13	CH132	J6	39
14	CH133	J6	37
15	CH134	J6	36
16	CH135	J6	35
17	CH136	J6	34
18	CH137	J6	33
19	CH138	J6	32
20	CH139	J6	31
21	CH140	J6	30
22	CH141	J6	29
23	CH142	J6	28
24	CH143	J6	27
25	CH144	J6	26
26	CH145	J7	50
27	CH146	J7	49
28	CH147	J7	48
29	CH148	J7	47
30	CH149	J7	46
31	CH150	J7	45
32	CH151	J7	44
33	CH152	J7	43
34	CH153	J7	42
35	CH154	J7	41







- compatible with JLAB Flash-ADC 125MHz system
- Each board holds 10 preamplifiers, each preamplifier connects to 24 GEM strips resulting on a readout of 240 GEM strips per each readout board or X/Y coordinate.
- A pre-amplifier has GAS-II ASIC chips (3 chips per each preamplifier card) and provides 2.6 mV/fC amplification. A preamplifier has a peaking time of 10 ns. It consumes 50 mWatt/channel and has a noise <0.3 fC. The dynamic range of preamplifiers (where it is linear) is about 200 fC.
- Covers up to 2.4 (32) μs of a drift time.

Improved version of pre-amps is needed!

External tracking

- ✓ External GEM tracker (contribution of UVa) has been successfully integrated into GEM-TRD setup
- ✓ APV25 with SRS-readout

The APV25 Deep Submicron Readout Chip for CMS Detectors

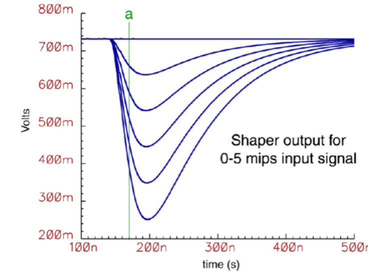
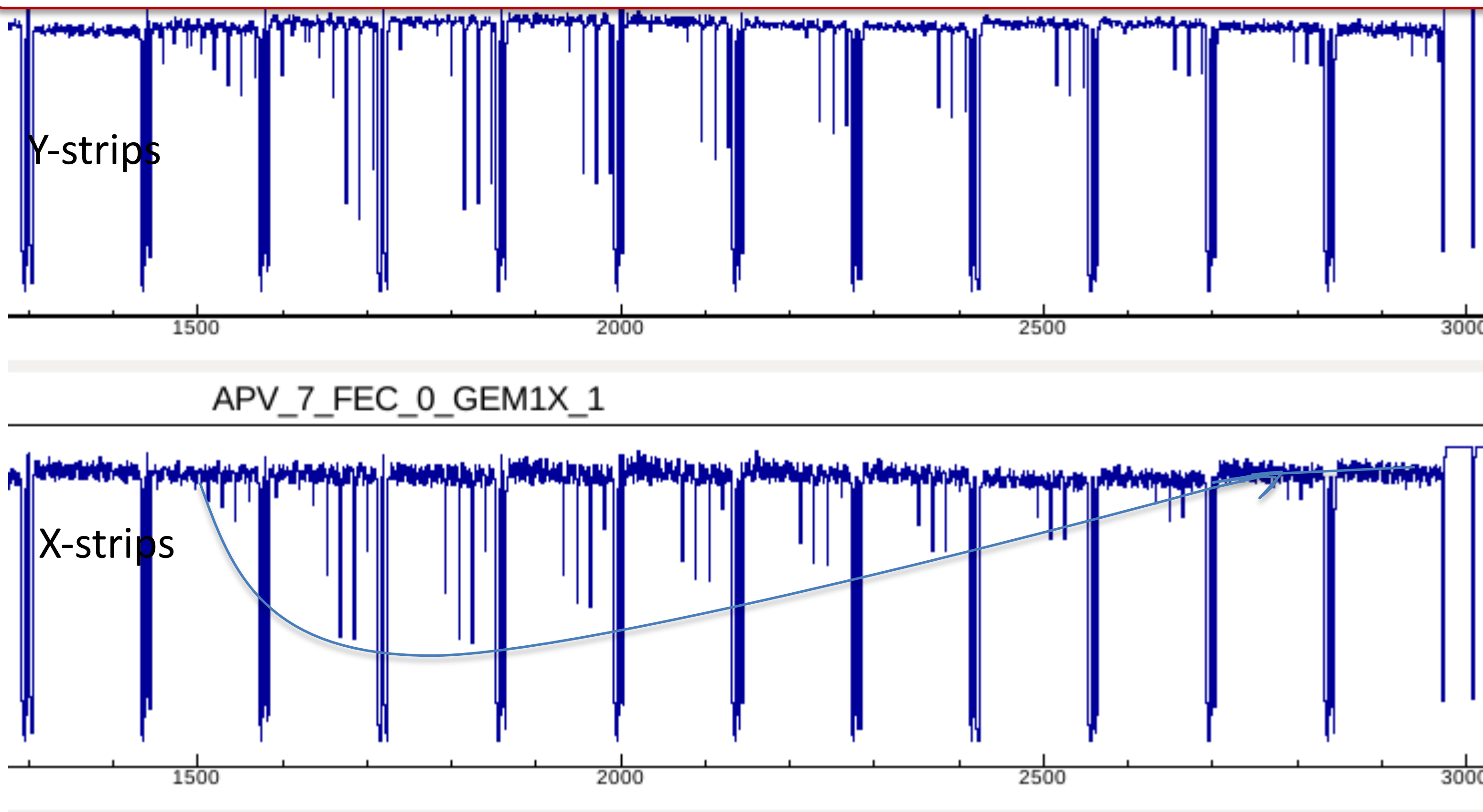


Figure 5. Response of Shaper (Hspice simulation).

GEM signal from APV, raw-signal (25ns window),
Total integration time ~ 250ns



Electronics:

	MHz	ns/bin	Peaking time	Range	Channels/chip cost	ADC bits	Shaper
FlashADC125	125	8	30ns	$1\mu s$ or stream	\$50/channel	12bit	External preamps (GAS-II) : -Undershooting -No baseline restorer
APV25	40	25	50ns	625ns	128 chan/chip		Analog output (no digitalization)
DREAM (CLAS12)	40	25	50ns		64chan/chip		Analog output (no digitalization)
VMM3 (ATLAS)	4	250	25-200ns		64chan/chip	10bit	L0 or continuous
SAMPA (ALICE)	10-20	100-50	160ns	Stream 3.2Gbit/s	32chan/chip 30\$/chip 1\$/channel	10bit	500ns- return to baseline Baseline restorer, DSP (zero-suppression, thr)

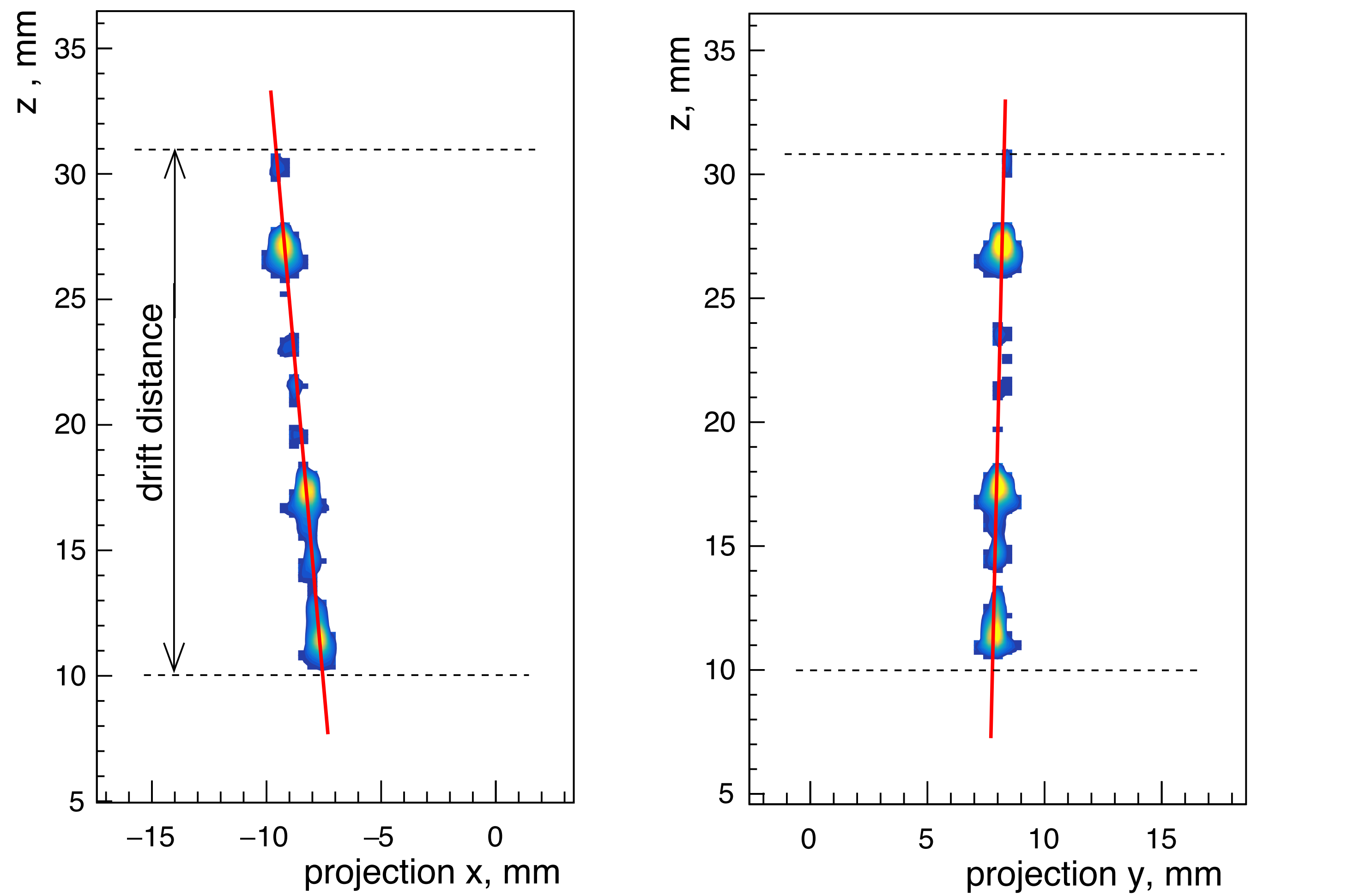
HV problems during the run

During the data tacking we had a
problem with powering all 3 modules (GEMTRD and 2 standard GEM trackers) :
After few uncontrolled HV jumps occurred, we were not able to operate GEMTRD module.
After removing it from the testbeam and testing it with a cosmics at Uva, module shows no damage or any misbehavior.

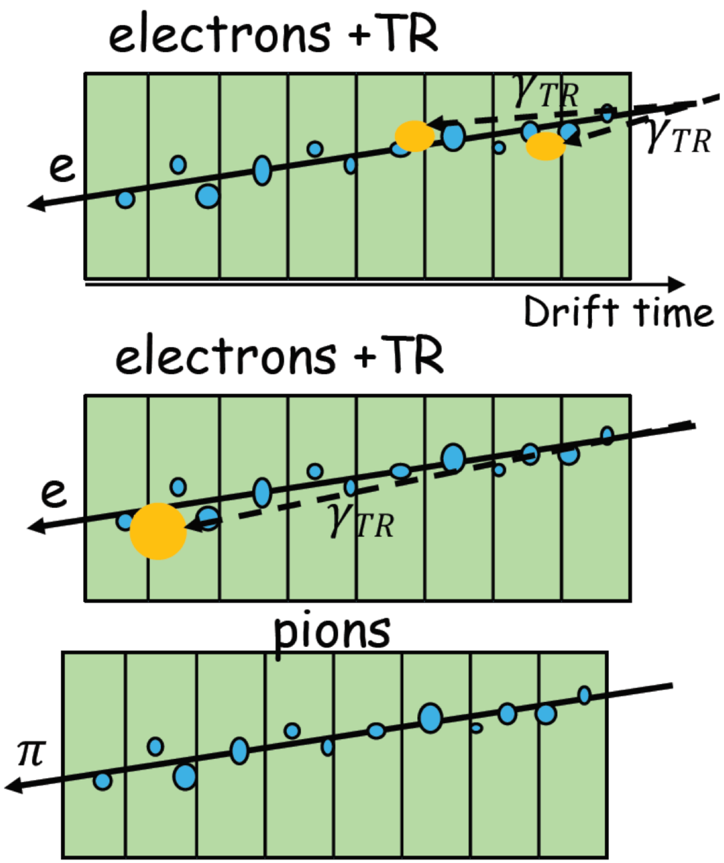
Moving currently to a standard NIM crate
 (used small one) and new HV power-supply
CAEN (N1470ET 4 channels 8kV/3mA) : expected delivery Sep 20.

GEMTRD tracking

Example of a single track seen at GEM-TRD (3D track segments in triple –GEM detector acting in a μTPC mode)



GEANT4: electron and pion comparison



Soft TR-photons:

- absorbs near entrance window, therefore have large drift time
- sensitive to dead volumes, like Xe-gap, cathode material.
- Increase of radiator thickness does not lead to increase of number of soft-photons (radiator self-absorption)

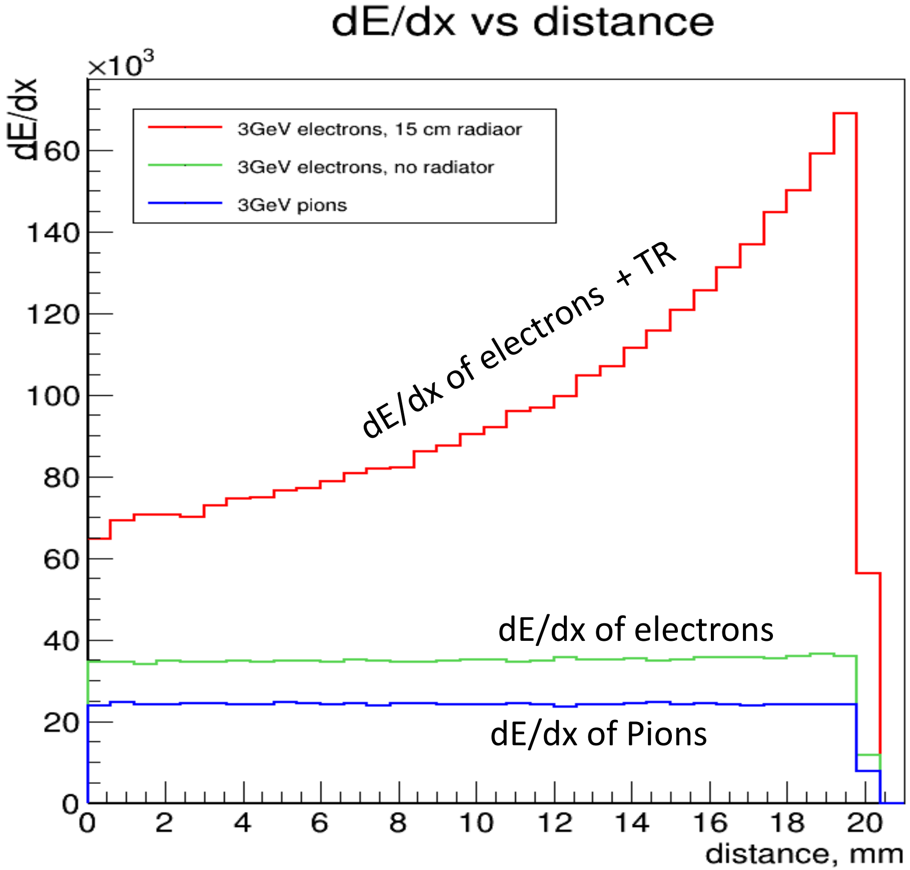
Hard TR-photons:

- Depending on energy of TR-photons, could escape detection (depends on detection length)
- Increase of radiator leads to increase of hard TR-spectra.

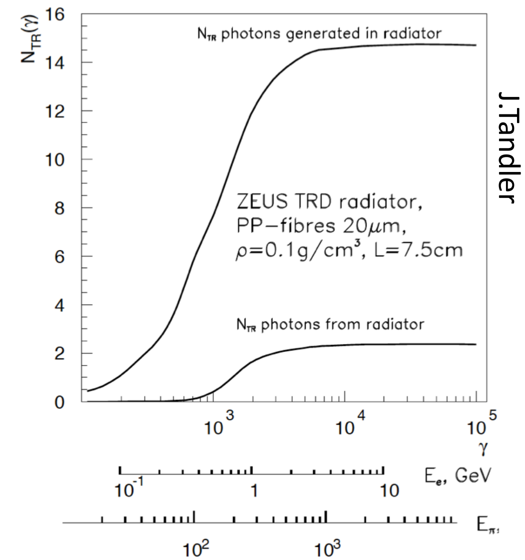
Separation/ Identification of TR-clusters and dE/dx clusters

GEANT4: electron and pion comparison

Energy deposition (dE/dx + TR) vs distance



e,π ~3 GeV



Pions does not produce TR photons up to energy ~ 100 GeV

One could estimate TRD performance with just e-beam, by comparing regions with and without radiator.

Note, that due to lower <dE/dx>, e/π rejection performance will be better.

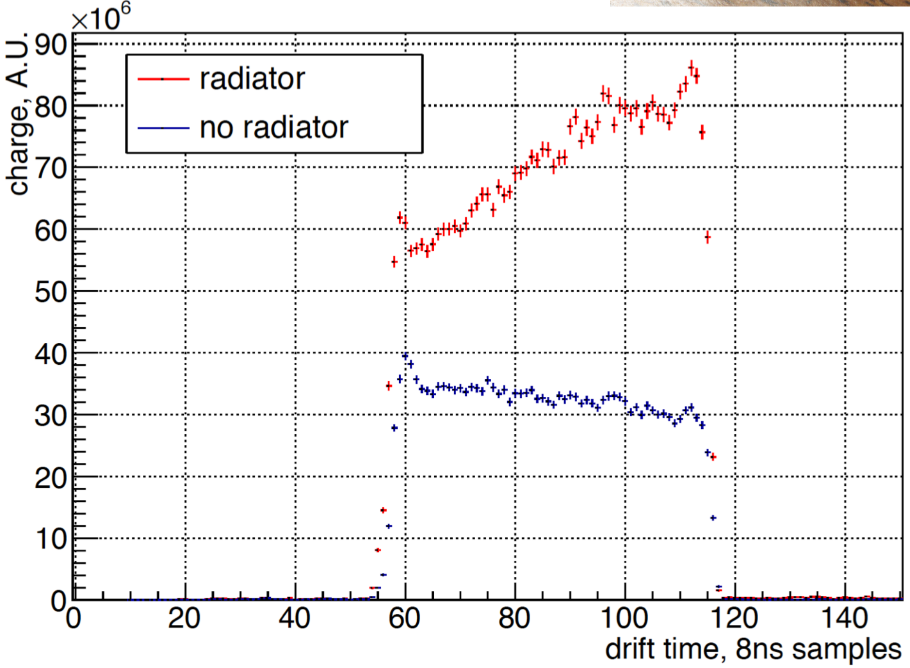
Yulia Furletova

Charge as a function of drift distance

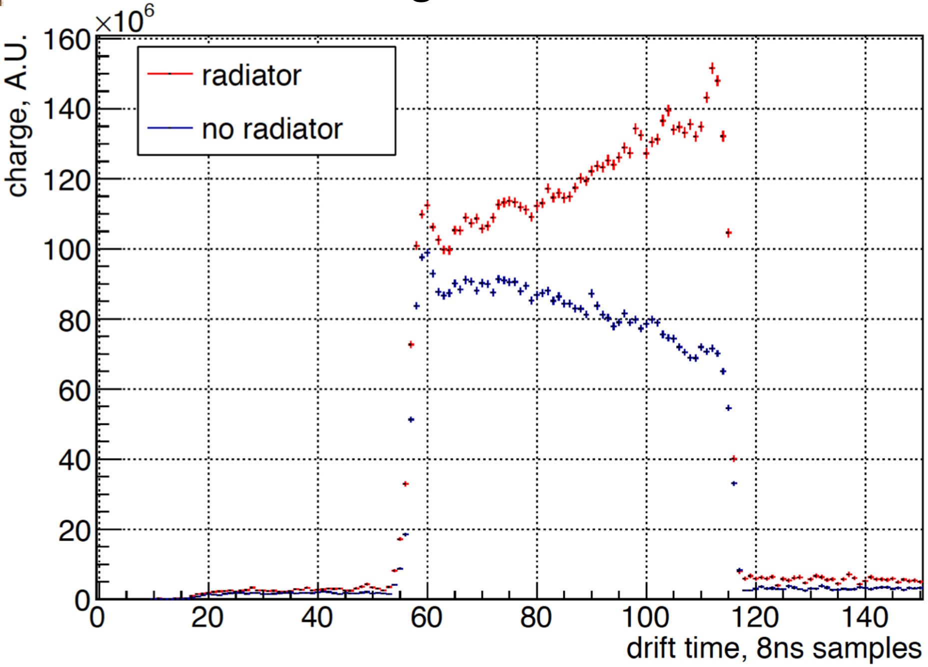
Fleece radiator:
Random oriented in 2D
Polypropylene fibers (20μm)

Regular foils:
~200 polypropylene foils (~13 μm thick) with spacers (~180μm) made from nylon net

Fleece

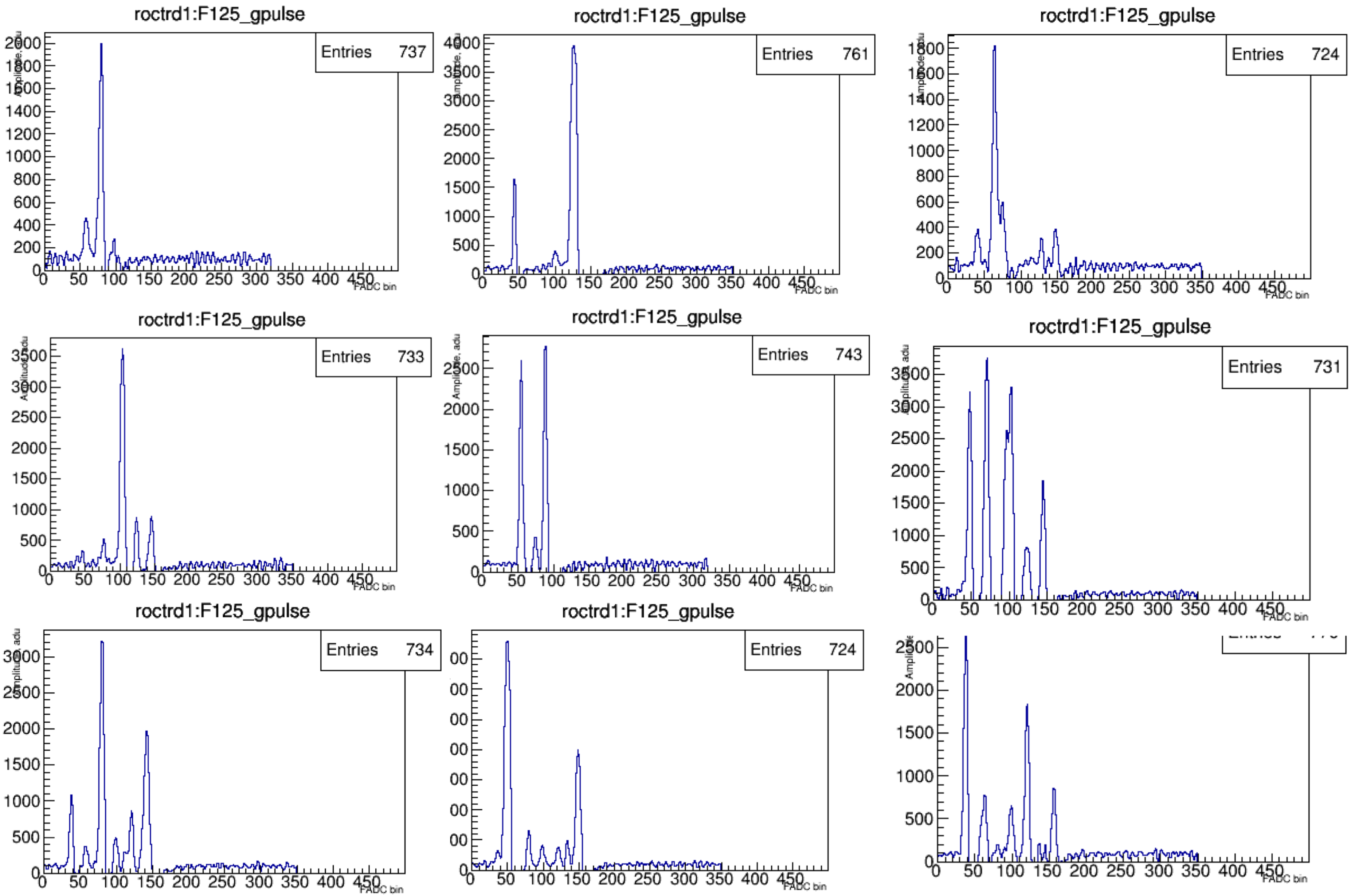


Regular foils

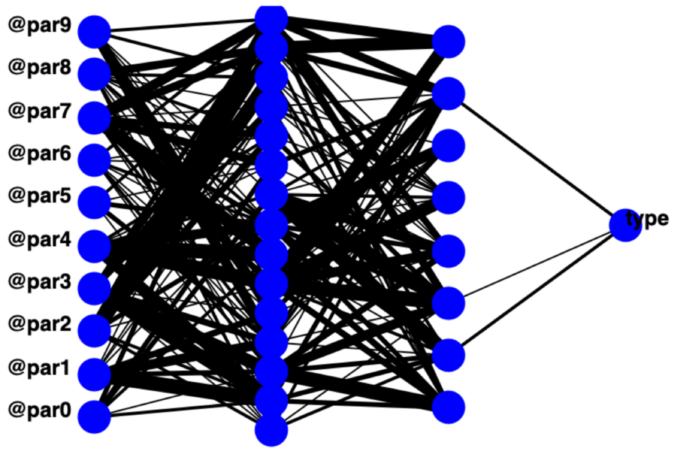


Yulia Furletova

Signals from GEMTRD using FlashADC125



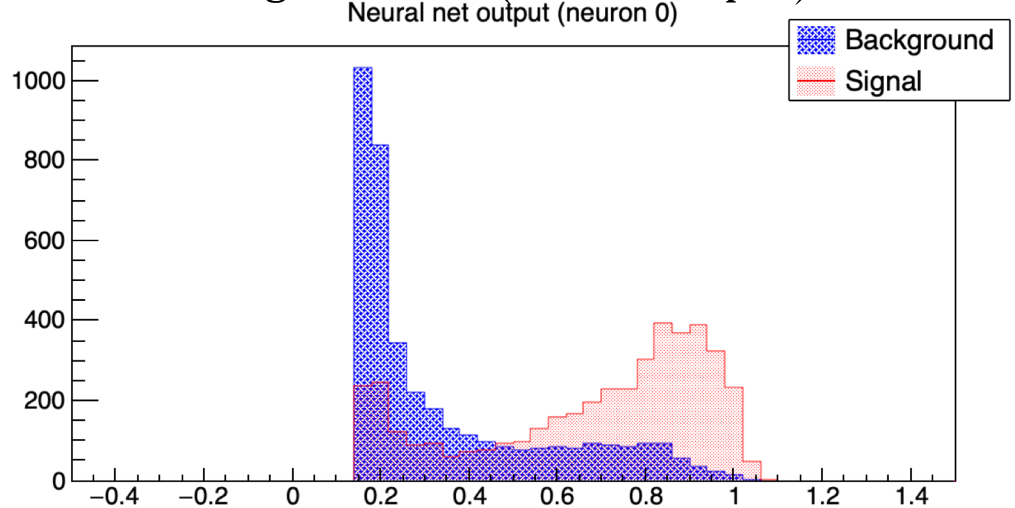
Machine learning technique



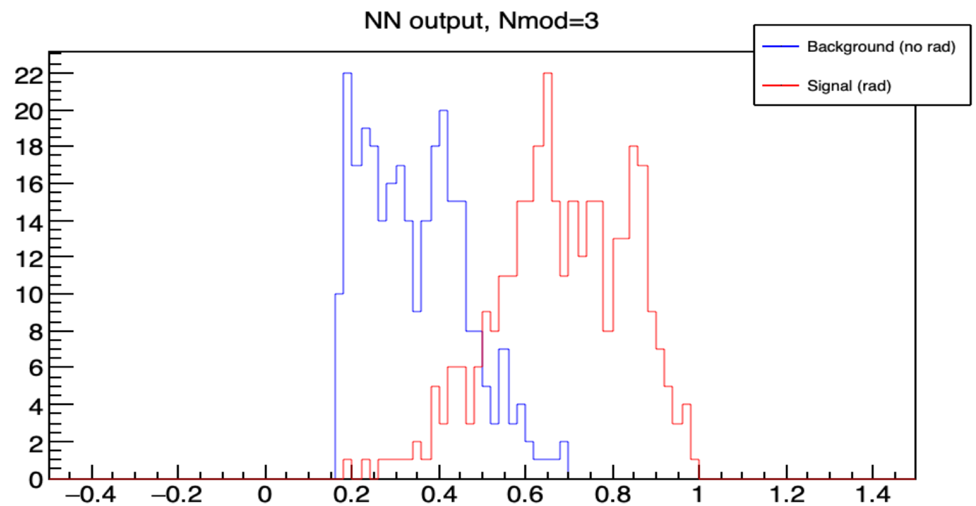
Upto 20 variables were used as input for likelihood and artificial neural network (ANN) programs, such as JETNET or ROOT-based (Multi-layer Perceptron).

We compared cluster search method and integrated charge within a bin (drift slice).

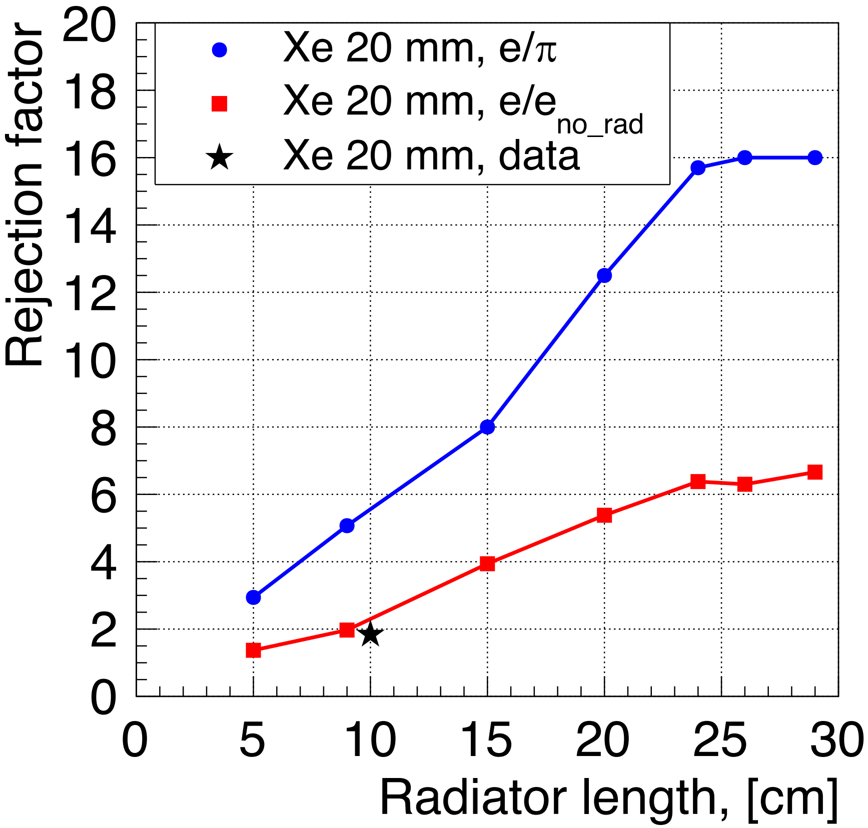
Multilayer perceptron output
for a single module (DATA sample)

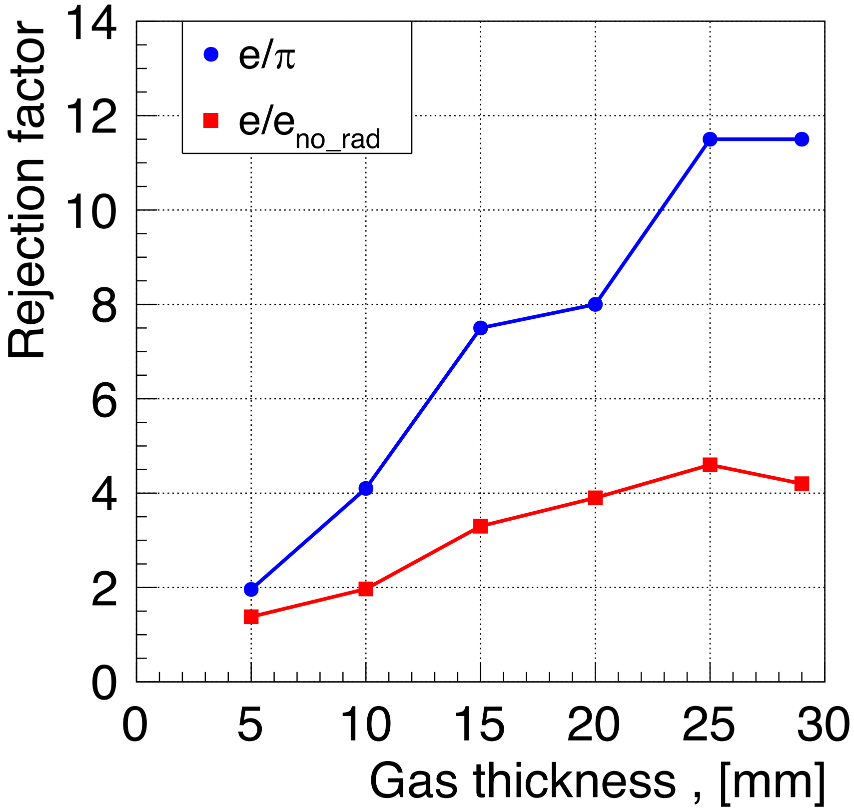


propagation for 3 modules (bottom) for real data sample



e/π rejection





Tacking into account a limited space between dRICH and EMCAL, a single module of ~15-16 could be achieved with a single module (20cm radiator and 2.5cm gas).

To Do

1) To measure a real e/π rejection factor we need a pion beam!!! (Fermilab, CERN testbeams have both e and hadron beams)

Problem: we do not have our own readout electronics (borrowed from JLAB Hall-D)

Solution (1) : use pions from $\rho - meson$ decays (real GlueX physics !)
There will be a commissioning run in November for DIRC at Glue-X for 2 weeks.
Our proposal is

- to install GEM-TRD setup in front or behind DIRC detector (need mechanical support)
- Integrate GEM-TRD into GlueX Data-acquisition data processing,
- Integrate GEM-TRD into post-processing (analysis)

Solution (2): use Fermilab or CERN testbeam, need a financial support for R/O, have a joint test-beam with
EMCAL (eRD1) to estimate a Global PID (e/π) performance

To Do

2) Finish gas installation of a gas mixing system as well as gas analyzer to perform gas–HV scan and to find an optimal mixture and HV settings for TRD operation.

3) Radiators

HERMES and ZEUS fleece radiator are not in production anymore (experts and manufactures has been contacted)
ATLAS-spacers also not available (meeting with ATLAS-TRD/T experts in February)

Have to start searching for a new TRD radiators (or manufactures)

Use the current setup to validate a performance of new TRD radiators.

To Do

4) Streaming readout for GEM-TRD operation.

Our project has been recognized and supported by Hall-D JLAB.
We got additional support for development of readout chain, including an implementation of Machine Learning on FPGA for online data processing and data reduction. Planning to perform in FY20.

Budget

This budget does not include items for R/O electronics and travel to Fermilab or CERN testbeam

Table 2: **Temple University-Gas System** FY20 request.

	Request	**-20%**	**-40%**
Gas supplies	$3,000	$2,000	$1000
Travel	$3,000	$2,000	$2,000
Overhead (58.5%)	$3,510	$2,340	$1,755
Total	**$9,510**	**$6,340**	**$4,755**

The table 3 below summarizes the Jefferson Lab budget request for FY20.

Table 3: **JLAB: Xe-gas and safety** FY20 request.

	Request	**-20%**	**-40%**
Gas safety	$4,000	$2,000	$2,000
Xe Gas	$15,000	$ 15,000	$ 8,000
Travel	$5,000	$4,000	$3,000
Overhead (ca 12%)	$3,010	$2,550	$ 1,696
Total	**$27,010**	**$23,550**	**$14,696**

The table 5 below summarizes the University of Virginia budget request for FY20.

Table 4: **UVA prototyping** FY20 request.

	Request	**-20%**	**-40%**
GEM-TRD with dedicated field cage	$6,000	$5,000	$4,000
Repair parts for prototype	$4,000	$3,000	$2,000
Travel	$5,000	$4,000	$3,000
Overhead (61.5%)	$3,075	$2,460	$1,855
Total	**$18,075**	**$ 14,460**	**$10,845**

Budget

This budget does not include items for R/O electronics and travel to Fermilab or CERN testbeam

Table 2: **Temple University-Gas System** FY20 request.

	Request	**-20%**	**-40%**
Gas supplies	$3,000	$2,000	$1000
Travel	$3,000	$2,000	$2,000

Table 5: **A total eRD22** FY20 request.

	Request	**-20%**	**-40%**
JLAB	$27,010	$23,550	$14,696
UVA	$18,075	$ 14,460	$ 10,845
Temple U	$9,510	$ 6,340	$ 4,755
Total	**$54,595**	**$ 44,350**	**$30,296**

Table 4: **UVA prototyping** FY20 request.

	Request	**-20%**	**-40%**
GEM-TRD with dedicated field cage	$6,000	$5,000	$4,000
Repair parts for prototype	$4,000	$3,000	$2,000
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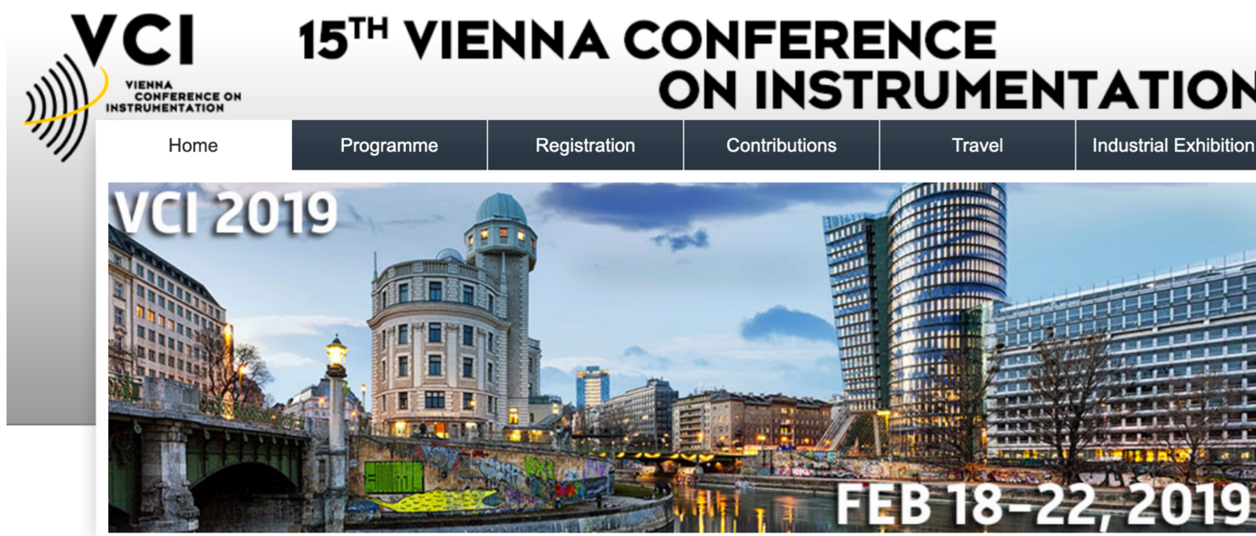
Conferences



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A new Transition Radiation detector based on GEM technology

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ABSTRACT

Transition Radiation Detectors (TRD) have the attractive feature of separating particles by their gamma factor. Classical TRDs are based on Multi-Wire Proportional Chambers (MWPC) or straw tubes, using a Xenon based gas mixture to efficiently absorb transition radiation photons. These detectors operate well in experiments with relatively low particle multiplicity. The performance of MWPC-TRD in experiments with luminosity of order 10^{34} cm^2s^{-1} and above, is significantly deteriorated due to the high particle multiplicity and channel occupancy. Replacing MWPC or straw tubes with a high granularity Micro Pattern Gas Detectors (MPGD) like Gas Electron Multipliers (GEMs), could improve the performance of the TRD. In addition, GEM technology allows one to combine a tracker with TRD identification (GEM-TRD/T). This report presents a new TRD development based on GEM technology for the future Electron Ion Collider (EIC). The first beam test was performed at Jefferson Lab (Hall-D) using 3–6 GeV electrons. A GEM-TRD/T module has been exposed to electrons with and without a fiber radiator. First results of test beam measurements and comparison with Geant4 Monte Carlo are presented in this article.

Summary

- Electron identification is very important for EIC physics. Due to a large hadron background expected in the forward (Hadron-endcap) region, a high granularity tracker combined with TRD functionality could provide additional electron identification - GEM-TRD/T

- GEANT4 simulation of GEM-TRD has been performed

- First test beam measurement has been performed , data has been analyzed and published !

- Looking forward to a collaboration with other eRD consortiums !

Thank you!

Backup